Nearshore Canyon Experiment: Analysis

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LONG-TERM GOALS

The long-term goals are to understand the transformation of surface gravity waves propagating across the nearshore to the beach, the corresponding wave-driven circulation, and the associated evolution of surfzone morphology.

OBJECTIVES

The objective of the Nearshore Canyon Experiment (NCEX) is to understand the effect of complex continental-shelf bathymetry on surface gravity waves and on the breaking-wave-driven circulation onshore of the irregular bathymetry. Primary objectives this year were quality control processing of all the data in anticipation of public release on 1 January 2006, and analysis of infragravity wave reflections and bathymetric changes. Additional objectives of our research are to test hypotheses for nearshore waves, currents, and morphological change with previously obtained observations.

APPROACH

Our approach is to test hypotheses by comparing model predictions with waves, currents, and morphological evolution observed on natural beaches.

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WORK COMPLETED

Field observations and numerical model results were used to investigate the formation of cusps on a natural beach (Ciriano *et al.,* 2005), and the effect of tides on cusp growth and development (Coco *et al.,* 2004*)*.

Seafloor roughnesses estimated with fixed (in space) and mobile (towed by an amphibious vehicle) altimeters were compared with each other, and shown to be similar (Gallagher *et al.,* 2005).

The previously observed large directional spread of sea and swell in the surfzone was shown to result from refraction by the currents of lower frequency shear waves (Henderson *et al., in press*).

Numerical simulations were used to suggest that eddies shed from the strong sheared flow close to shore contribute to the observed offshore decrease in shear wave phase speed (*Noyes et al.*, 2005).

A new estimator for wave directional properties was used to show that strong dissipation of shoreward propagating infragravity waves suppresses the excitation of infragravity edge waves (Sheremet et al., 2005).

Quality control methods for acoustic Doppler velocimeter data obtained in the surf and swash zones were evaluated and improved (Elgar *et al.,* 2005).

An inverse method was developed to decompose observations of pressure and velocity on each side of a submarine canyon into incident waves, waves reflected by the canyon, and waves transmitted across the canyon, and the resulting reflection and transmission coefficients were compared with theory (Thomson *et al.,* 2005).

Models for bedload transport in two-phase sheet flow were driven with observed velocities to examine the importance of phase-lags between the bed stress and flows outside the wave boundary layer to swashzone sediment transport (Hsu and Raubenheimer*, in press*). Simplified models were used to test parameterizations for sediment transport, and compared with observed sandbar migration (Hsu *et al., in review*).

GPS-tracked drifters were used to investigate surfzone circulation, including rip currents and eddies, over irregular bathymetry (Schmidt *et al., in press*).

Surface fluid velocities measured in the surfzone with FOPAIR radar were compared with *in situ* flow measurements collected during SwashX (Farquharson *et al., in press*).

As part of NCEX, over 100 sensors were deployed offshore, near, and onshore of two submarine canyons (Figure 1). In addition, bathymetric surveys extending from above the shoreline to about 8-m water depth were conducted almost weekly along several km of the coast. The survey data have been processed, and are available to the public on the WWW (cdip.ucsd.edu/models/ncex/bathy/ and science.whoi.edu/users/elgar/NCEX/maps/bathymetry2.html). Processing of surf and swashzone measurements is complete, and a database of wave heights, wave directions, wave-orbital velocities, and mean currents is under construction.

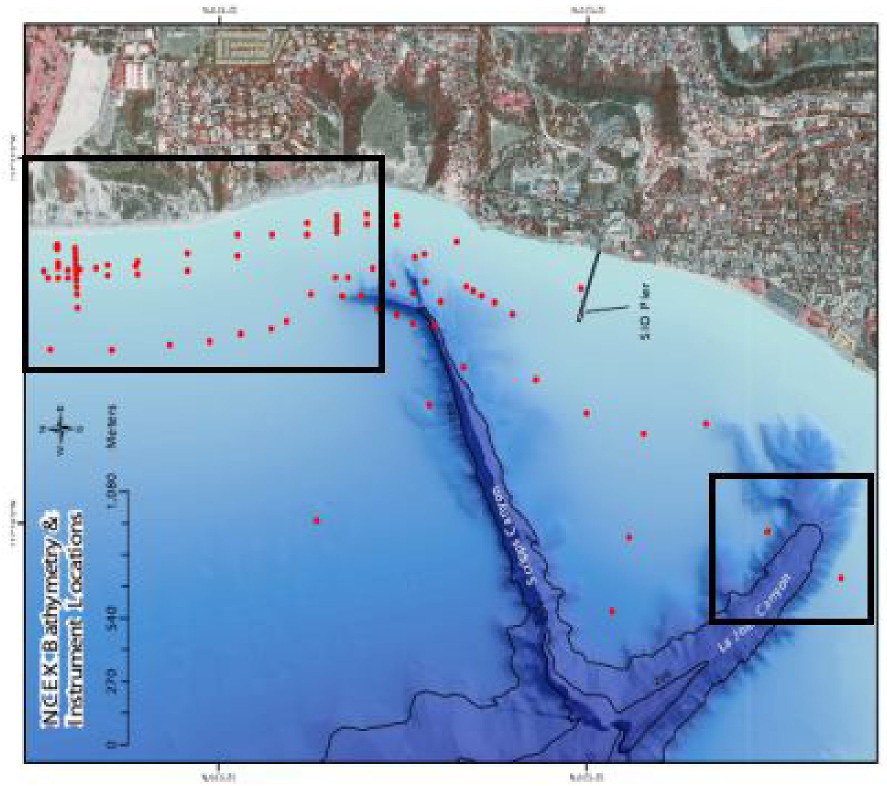

Figure 1. The NCEX instrument array (red circles) and bathymetry (contours are m relative to mean sea level). The black boxes indicate the instruments used for the studies (discussed below) of infragravity wave reflection (box on right side) and bathymetric changes (box on left side). [Instruments were deployed at over 100 locations offshore, near, and onshore of two submarine canyons that extend from deep water almost to the shoreline.]

RESULTS

The observed reflection of ocean surface gravity waves with periods between 20 and 200 s from the steep-walled La Jolla submarine canyon is consistent with long-wave theory (Figure 2) (Thomson *et al.,* 2005). For example, the theory accurately predicts that as much as 60% of the energy of waves approaching the canyon normal to its axis was reflected (Figure 2a). The nearly complete transmission (reflection coefficient, $R^2 = 0$) of normally incident waves with wavelengths nearly twice the canyon width (frequency of 40 mHz) also was predicted accurately. Although waves approaching the canyon at oblique angles cannot propagate over the canyon, total reflection ($R^2 = 1$) was observed only at frequencies higher than about 20 mHz, with lower frequency energy partially transmitted across, analogous to the quantum tunneling of a free particle through a classically impenetrable barrier. The observed reflection of obliquely incident waves is somewhat less than theoretical predictions (Figure 2b), possibly because the non-uniformity of the La Jolla Canyon profile (Figure 1), neglected in the theoretical formulation, becomes increasingly important as the incidence angle increases. During the 4-week observational period, on average more than half the incident infragravity wave energy was reflected by La Jolla submarine canyon, showing that reflection contributes significantly to the near-canyon infragravity wave energy balance.

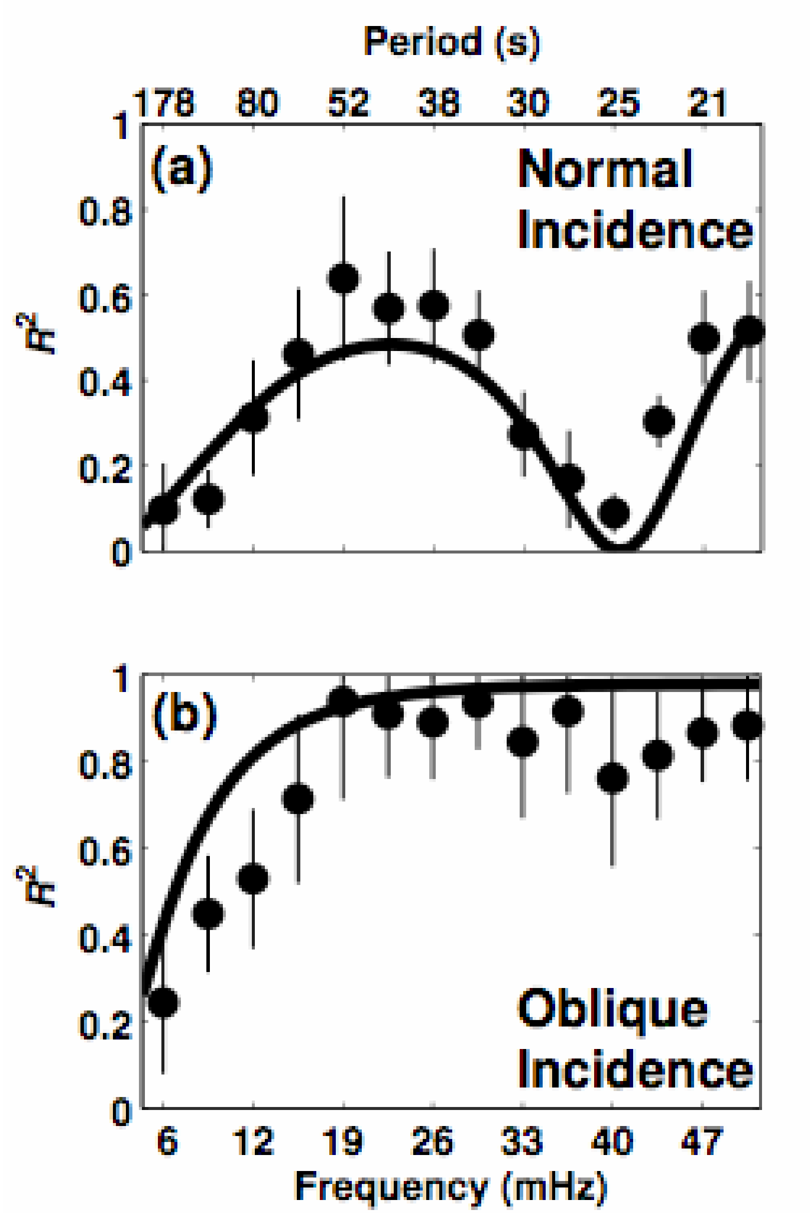

Figure 2: Observed (symbols) and theoretical (curves) reflection coefficients R^2 versus frequency (or period) for (a) normally and (b) obliquely incident waves. The curves are based on linear long-wave theory for a rectangular approximation of the canyon cross-section with depth h = 115 m and width W = 365 m. Circles are the averages (over 50 individual 1-hr long data records) of the nonlinear inverse estimates of R^2 at each frequency and vertical lines are ± one standard deviation of the estimates. [Reflection coefficients as a function of wave frequency and wavelength for waves approaching the canyon perpendicular to its axis and for waves approaching at oblique angles. For both theory and observations, reflection increases from nearly 0 for 200-s period, normally incident waves to almost 60% for 50-s waves, and then decreases to almost 0 for 25-s waves (with wavelength twice the width of the canyon). Reflection increases with frequency for higher frequency waves. For obliquely incident waves, theoretical and observed reflection increases from 20% for 200-s waves to approximately 100% for waves with periods less than about 50 s. Observed reflection is somewhat lower than the predicted 100%, possibly owing to deviations of the canyon geometry from the rectangular shape used in the theory.]

A primary objective of the Nearshore Canyon Experiment (NCEX) was to test models for waves propagating across steep bathymetry in shallow water, producing complicated flows in the surfzone. These flows carry pollutants, swimmers, and sediment. For example, bathymetric surveys show that a large wedge of sand accreted in Black's Bowl (roughly at cross- and alongshore distances 25 and 1650 m, respectively), and a small sandbar formed north of the bowl between Oct 6 and Oct 13 (Figure 3). Owing to refraction across the offshore submarine canyons, 1.5-m-high waves during a storm on Oct 9 - 10 approached the beach from the north at the northern end of the study area and from the south at the southern end (not shown). The resulting alongshore flows measured in 1- and 2.5-m water depths converged on Black's Bowl, whereas the flows in 5-m water depth diverged from the region of the bowl (Figure 3).

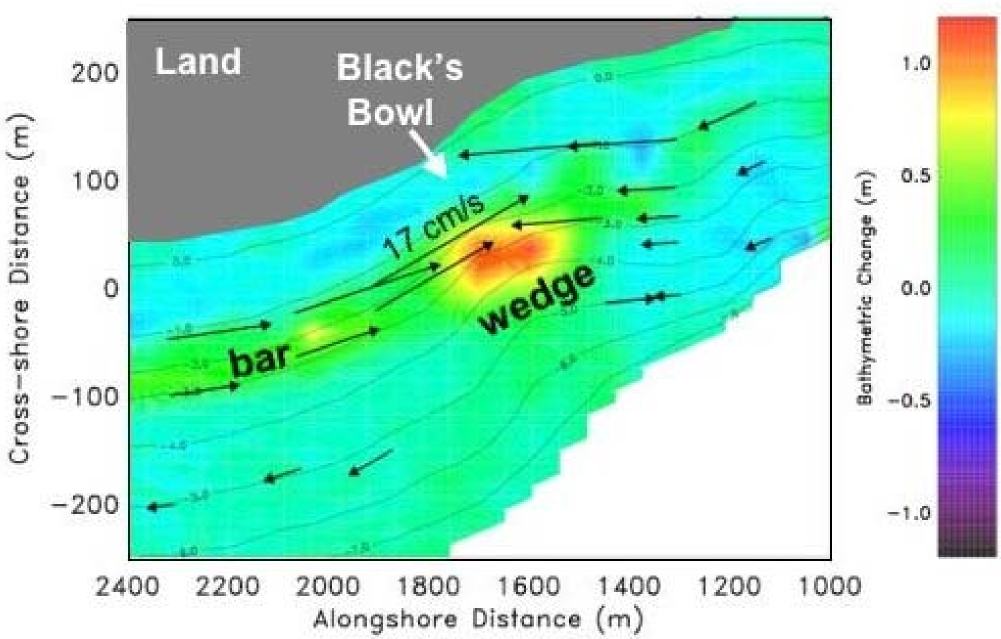

Figure 3. Observed bathymetric change between Oct 6 and Oct 13 (color contours) and alongshore flows (arrows) averaged over the weeklong period. [A wedge of sand roughly 75-m wide (cross-shore), 200-m long (alongshore), and 1.0 m high accreted in 3-m water depth. Accretion was less (about 0.3 m) north of the wedge, forming a sandbar. Alongshore flows converged at the wedge, with maximum flows (averaged over a week) of about 17 cm/s.]

Bathymetric changes predicted with a simple energetics model (e.g., Bailard, 1981) averaged over quadrilateral regions surrounded by flow measurements are within 30% of the observations at most locations (Figure 4). The model simulations suggest that the alongshore gradients of the alongshore flows account for roughly 20% of the accretion in the wedge, but caused erosion elsewhere (not shown). In contrast with prior sandbar migration studies (e.g., Gallagher *et al.,* 1998), convergence of the cross-shore mean flows was weak, and is predicted to contribute only 10% to the formation of the sandbar and the wedge. Instead, the bar and wedge formation are predicted to result primarily from cross-shore convergence of transport owing to cross-shore gradients of the wave skewness (peakedness of the wave shapes).

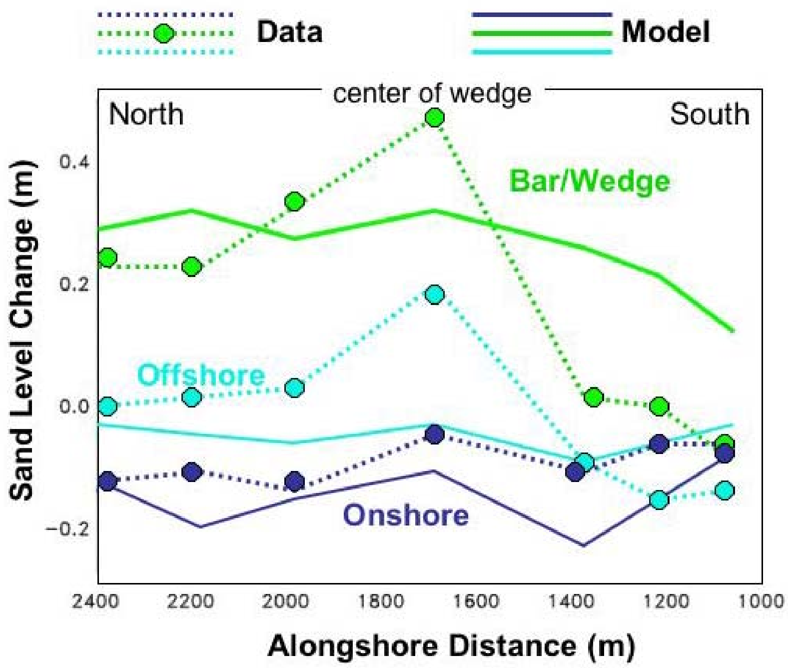

Figure 4: Observed (dotted curves and symbols) and predicted (solid curves) sand level changes between 0- and 1-m water depth (dark blue curves, labeled Onshore), between 1- and 2.5-m water depths (green curves, labeled Bar/Wedge), and between 2.5- and 5-m water depths (light blue curves, labeled Offshore) versus alongshore distance. [Predicted sand level changes typically are most accurate north of the wedge center.]

IMPACT/APPLICATIONS

The field observations have been used to verify and improve models for nearshore and surfzone waves, circulation, and morphological change, and to ground truth remote sensing techniques to estimate nearshore currents. The comparison of model predictions with observations has increased our ability to predict nearshore bathymetric change, including the migration of sandbars across the surfzone.

RELATED PROJECTS

The Duck94 and SandyDuck observations are being used to test components of the NOPP nearshore community model, as well as other models for nearshore waves, currents, and bathymetry.

The studies of nearshore morphology are in collaboration with an Army Research Office project to investigate onshore sediment transport and sandbar migration, and with NSF projects funding swashzone research, numerical modeling, and undergraduate fellows.

Studies of surfzone circulation and mixing using drifters are in collaboration with a Sea Grant project.

Observations of nearshore bedforms are being used as part of Mine Burial Program studies (with E. Gallagher).

NCEX observations are being used in collaboration with modeling studies and as ground truth for remote sensing of nearshore currents.

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